Chapter 8
Benthic Invertebrate Community

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8.0 BENTHIC INVERTEBRATES COMMUNITY

Intertidal and shallow subtidal waters are generally recognized as important and biologically productive, although focus is often placed on salt marsh and eelgrass (*Zostera marina*) beds within this region. Other key habitats are the unvegetated intertidal mudflats and shallow subtidal soft bottom, which provide distinct values to bays and estuaries. The communities of benthic invertebrates and demersal fishes are distinct from those in the eelgrass vegetated habitat. Takahashi (1992) found that the number of species of benthic invertebrates in central San Diego Bay inhabiting both bare soft bottom and eelgrass vegetated bottom in common was a small fraction of the number of benthic invertebrates observed in these habitats separately, illustrating that the benthic invertebrate communities in these habitats are certainly distinct. Many species of fish occurring in eelgrass habitat also occur in unvegetated habitat, while some fish are more dependent on unvegetated areas and its particular invertebrate fauna. One example is the recreationally and commercially important California halibut (*Paralichthys californicus*) (Allen 1982, Kramer 1990), as well as diamond turbot (*Pleuronichthys guttulatus*), round stingray (*Urobatis halleri*), and a variety of gobies (Gobiidae). Gobies are among the most abundant bay and estuarine species in bare soft bottom habitats and act as an important link in food chains, forming a link between their invertebrate prey and their vertebrate predators. Gobies make up a large portion of the diets of several fish species (MacDonald 1975), as well as shorebirds (Brothers 1975) and California least terns (*Sternula antillarum browni)* (Montgomery and Edwards 1988).

In addition to serving as a forage area for fish and birds, the invertebrate fauna in bare soft bottom habitats perform a variety of other crucial functions. Molluscs, polychaete worms, small crustaceans, and other invertebrates serve to break up detritus, mineralize organic waste, and return chemicals and organic matter to the water column (Levin et al. 2001). The suspension feeding of bivalves in particular can serve to improve water clarity and quality through removal of particulates and control of plankton blooms. In addition, some infaunal invertebrates help stabilize sediments and their community by preventing disturbance associated with shifting sediments (Thrush et al. 1996).

The restoration of Batiquitos Lagoon provided an opportunity to study the development of benthic communities following the restoration of tidal flow. The benthic community characterization program was principally structured to provide an indication of the relative availability and abundance of infaunal and epifaunal organisms within the various regions of Batiquitos Lagoon. This chapter presents the results of epibenthic and infaunal sampling and discusses the results with regard to changes in the community structure over the 10 post-construction monitoring years.

8.1 METHODS

Benthic surveys were conducted at five sampling stations throughout the lagoon (Figure 8-1). These stations coincided with Stations 1 through 5 of the onshore fish community sampling (refer to Chapter 5). Sampling was conducted in January and October in years 1, 2, 3, 5, and 10

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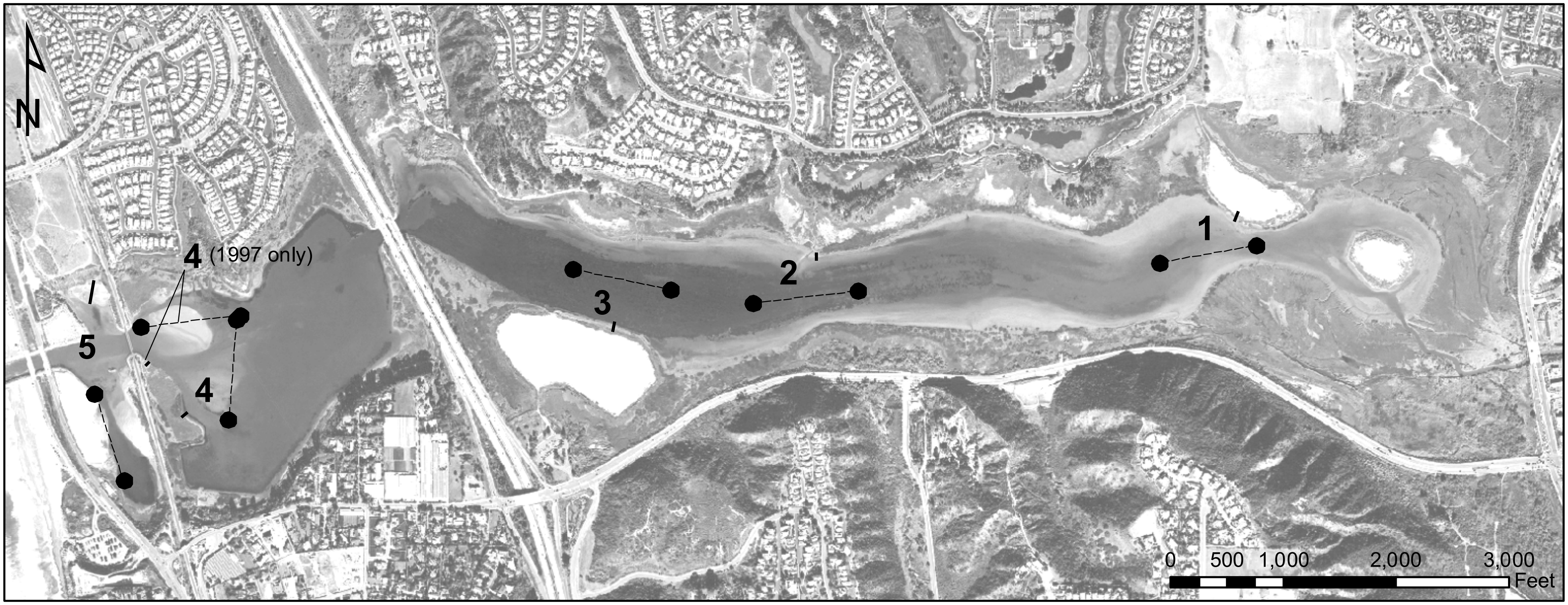

Onshore benthic and epibenthic sampling transects

Offshore epibenthic sampling (collected in fish sampling gear)

Benthic invertebrate sampling stations

Figure 8-1

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(1997, 1998, 1999, 2001, and 2006) following the completion of restoration. Both infaunal and epifaunal surveys were completed.

8.1.1 Infauna

At each station, a transect was established perpendicular to the shoreline, running through the station marker (PCV stake) at each sampling location (Stations 1 through 5). The +3-foot Mean Lower Low Water (MLLW) (high intertidal zone), +1-foot MLLW (low intertidal zone), and –2-foot MLLW tidal elevation (shallow subtidal zone) was determined along the transect. (The permanent onshore station marker is located at the +1-foot MLLW elevation.) A sediment core was collected along the transect line at the +3-foot MLLW tidal elevation using a 15-cm diameter corer inserted to a sediment depth of 15 cm. Two more cores were collected one meter to the left and one meter to the right of the transect line. All three cores were rinsed through a 1.0-mm sieve. The collection process was repeated at the +1-foot MLLW and the –2-foot MLLW tidal elevations. The sediment area sampled by each core was 0.018 m^2. Organisms from each sample were placed in containers, preserved in a buffered 10% formalin:seawater solution, and transported to the laboratory for subsequent analysis.

An additional core of sediment was collected at each elevation along the transect line and transported to the laboratory for grain size analysis.

Additional collections done during the first three sampling events involved processing a second set of samples through a 0.5-mm sieve. In October 1998, however, the Batiquitos Lagoon Technical Steering Committee recommended this be dropped due to the minimal additional information obtained from the work, with the effort reallocated to expansion of the epibenthic sampling efforts described below. Data collected from the 0.5-mm samples is not presented in this report.

Core collection unavoidably captured the biota occurring on the surface of the sampled core, as well as in the water column for the –2-foot MLLW samples. Therefore, the collected samples often included epibenthic and open water organisms along with the infauna. Although captured fish were removed from the samples, all other organisms were retained and worked up along with the infauna. The presence of epifaunal invertebrates will be noted in the results section where applicable.

After approximately one week, organisms collected from the benthic cores were transferred in the laboratory into 70% isopropyl alcohol, or ethanol. During years 1 and 2, samples were stained with rose bengal. In the following years, this was eliminated from the protocol after it was determined that the stain was not needed. All individuals in each replicate sample were identified to the lowest practical taxonomic level and then counted. The occurrence of nematodes, foraminiferans, and pelagic organisms not classified as infauna or which were too small to quantify were noted; however, no attempt was made to quantify these organisms. Because the benthic monitoring program was intended to broadly characterize the communities of infaunal and epifaunal organisms within the various regions of Batiquitos Lagoon over time, species level classification was not deemed necessary. Rather, data were analyzed and presented in logical, higher-order taxonomic groups.

After enumeration, the organisms of each replicate were grouped by phylum and weighed to determine the wet weight of each phylum. Wet weight was determined by transferring an entire sample (or phylum), including alcohol, onto a paper towel and blotting quickly to remove excess liquid from the animals. Organisms were then transferred to a tared weighing dish and weighed to the nearest 0.0001 gram (g) using an analytical balance. All samples were returned to the alcohol solution and archived for future reference.

8.1.2 Epifauna

The epibenthic invertebrate sampling program made use of both a focused investigation completed using a 1-m^2 quadrat and a more expansive field effort undertaken as a part of the fish community surveys. For the quadrat survey, a 1-m^2 quadrat was tossed randomly within each of the three tidal elevations utilized for the infauna surveys (+3 feet, +1 foot, and -2 feet MLLW), and all epifaunal organisms present on the surface of the substrate within the quadrat boundary were recorded. Three replicate tosses were completed at each tidal elevation. Macroalgae present in the quadrat were also recorded. Poor water visibility generally precluded making a visual assessment of the bottom when the quadrat was placed in the water at the shallow subtidal (-2 feet MLLW) elevations. The 1-m^2 square enclosure was therefore utilized in place of the epibenthic quadrat at this elevation. During the enclosure work for the fish community sampling program, all epibenthic invertebrates captured were recorded. This technique precluded the ability to determine percent coverage of macroalgae or other organisms, but was effective for quantifying macroinvertebrate resources.

By the second monitoring year, it became apparent that the quadrat sampling effort to characterize epibenthic communities was inadequate. Most epibenthic organisms are highly mobile and vacated the mudflat shoreline during the low tides targeted for the survey work. As a result, observations from the 1997 epibenthic sampling yielded little in the way of characterizing the epibenthic community known to exist from observations made during other sampling efforts. Further, the frequency of sampling of the epibenthic communities was found to be inadequate due to population explosions and collapses observed during brief periods that were only apparent within a single quarter. Such episodic events could be missed in the biannual epibenthic sampling effort. To address these concerns, resources diverted from the 0.5-mm sieve sampling program were applied to a quarterly epibenthic analysis based on epibenthic by-catch within the collected fish community samples. Beginning in October 1998 (year 2), during the completion of fish studies, the incidental by-catch of epibenthic invertebrates were collected, identified, and counted to further enhance the detection of epibenthic organisms and characterize their distribution, composition, and rough abundance within the lagoon. Because of the incidental nature of these collections, density information cannot be generated from the count data.

Only representatives of those organisms that could not be positively identified in the field were collected for subsequent laboratory taxonomy and voucher collections. These individuals were preserved in a 10% formalin:seawater mixture and transported to the laboratory for identification.

8.1.3 Data Analysis

Following the laboratory workup, the collected data were assembled for analysis and preparation of figures and tables. Data were analyzed to identify spatial and temporal trends in benthic invertebrate density and biomass. Differences in density (individuals/m^2) and biomass (g/m^2) among stations, tidal elevations, and sampling events were analyzed for all invertebrates captured within the hand-held coring device. Repeated-measures analysis of variance (ANOVA) was used to test for differences among factors and the repeated measures. ANOVA model factors included station (5 levels; Stations 1-5) and sample elevation (3 levels; -2, +1, and +3 feet MLLW). The repeated measures consisted of the biannual sampling events of sampling years 1, 2, 3, 5, and 10. All factors, and the repeated measures, were analyzed as fixed effects in the ANOVA model. The between effects replication consisted of the three replicate cores (n=3) for each elevation at each station.

Whenever the repeated measures model resulted in statistically significant differences for the station, elevation, or sampling event factors, post-hoc multiple comparisons tests were used to evaluate where differences occurred among the levels within each factor. Tukey's Honestly Significant Differences Tests (Tukey's HSD) were used to make independent pairwise comparisons among factor levels. This allowed determination of which factor levels could be grouped and considered as similar and where differences occurred that allowed groups to be considered significantly different from one another. All data were analyzed and plotted using Statistica 7 and Excel software for Windows®.

No statistical analyses were performed on the epibenthic data due to the limited sampling intensity and high variability of the results from the 1-m^2 quadrats, as well as the incidental nature of the macroinvertebrate collection from the fishing gear.

8.1.4 Pre-Restoration Data Review

Pre-restoration data on invertebrate resources at Batiquitos Lagoon are limited and were generally oriented towards evaluation of the availability of invertebrate food resources for fish and birds. Available data include observations by Mudie et al. (1976) and MacDonald and Feldmeth (1985), reviewed in the Revised Draft Batiquitos Lagoon Enhancement Plan (California Coastal Conservancy 1987), and sampling done in 1988 by Michael Brandman Associates (MBA). Additional sampling was done by MEC Analytical Systems, Inc. (MEC) in August 1988 at a low water condition with extensive mudflats available in order to establish a baseline for the current stocks of food resources for birds at the lagoon. Later work by Wetlands Research Associates (WRA) collected infaunal and epifaunal samples; however, the infaunal samples were archived for potential future examination only (WRA 1994 and 1997). A table of epifauna observed was presented. Although sampling in these studies was conducted by different methods, an understanding of the change in community composition following the restoration was gained by reviewing these data.

8.1.5 Study Program Limitations

A complication to the benthic sample collection arose from the inability to accurately determine the true tidal elevations within the lagoon over the course of the 10-year monitoring period due to the absence of any tidal monitoring within the lagoon. The tidal lag and muting were variable and considerable; therefore, only rough estimations of the location of the +3, +1, and –2-foot elevations could be made based on predicted ocean tides, the daily history of the tides on the sampling day, and observations of indicators of inundation frequency (vegetation, topography, wrack lines). It is likely that over time, the shoreline sampled in the +3 and +1-foot elevations areas had more variable inundation times, with extended inundation durations associated with incomplete drainage in some cases and in others, reduced inundation durations associated with the elevation of the shoreline due to sedimentation (see Chapter 1). This variability should be considered during review of the collected data.

The complications to the deployment of fisheries equipment described in Chapter 5 also apply to the collection of the epibenthic organisms, with interruption of the net pull by eelgrass and overlapping transects due to loss of available sampling area (Stations 4 and 5).

8.2 RESULTS

A summary of the density and biomass of benthic infauna from the 10-year monitoring program is presented in the following sections, figures, and tables, as well as a summary of epifaunal abundance. Note that there are temporal gaps in the survey dates (no sampling done in 2000, 2002, and 2004).

8.2.1 Infauna

Density

During the 10-year post-restoration monitoring program, infauna from 12 phyla were collected (Table 8-1). Additionally, nematodes were noted to be present at all elevations, stations, and time periods, though they were not enumerated or weighed. As discussed above, some species in the samples were epifauna or pelagic fauna that were captured along with the infauna during the sample core collection process. The abundance of organisms was highly variable between seasons and sampling years. Infauna were most abundant in the first year post-restoration, when the gastropod *Tryonia imitator* was captured in very high densities (as dense as 51,642 per m^2 at Station 1 in January 1997) from the top of the sample cores. Overall infaunal densities were lower in years 2, 3, and 5, then slightly higher in year 10 (Figure 8-2). Differences in infaunal density between sampling periods were found to be significant ($p<0.001$).

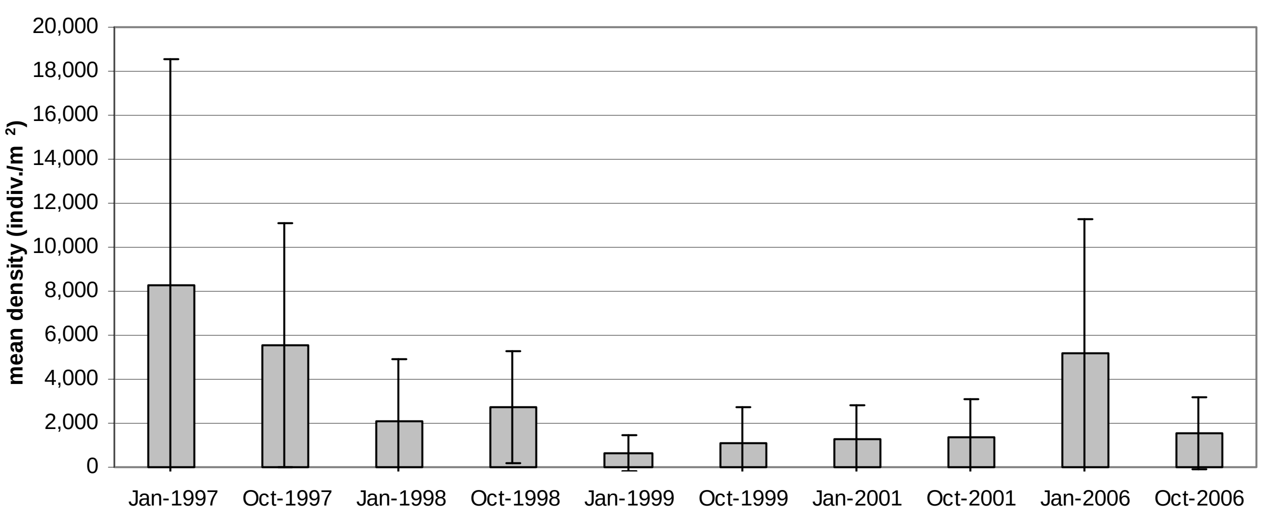


Figure 8-2. Mean density (indiv/m^2) of infauna during each sampling event ($\pm$ 1SD), n=45.

Table 8-1. Mean infauna density (individuals/m^2) by taxon at all stations at Batiquitos Lagoon (1997-2006).

		Monitoring Period									
		Year 1		Year 2		Year 3		Year 5		Year 10	
Phylum	**Taxon**	**Jan-1997**	**Oct-1997**	**Jan-1998**	**Oct-1998**	**Jan-1999**	**Oct-1999**	**Jan-2001**	**Oct-2001**	**Jan-2006**	**Oct-2006**
Annelida	Class Echiura	-	5	-	-	-	-	-	-	-	-
	Class Oligochaeta	11	-	-	-	-	-	-	-	-	-
	Class Polychaeta	1,728	1,144	1,477	706	133	578	291	634	3,746	579
Arthropoda	Order Amphipoda	18	561	49	145	45	111	229	123	862	263
	Order Cumacea	-	4	1	-	-	-	-	-	-	5
	Order Decapoda	-	3	3	4	1	5	4	14	4	4
	Order Diptera	-	107	1	15	115	-	-	60	-	-
	Class Insecta	-	-	-	50	-	98	210	162	-	-
	Order Isopoda	-	45	1	88	54	96	25	148	6	136
	Order Mysidacea	-	-	-	8	-	-	177	18	-	-
	Class Ostracoda	63	13	1	4	-	-	-	-	-	-
	Order Stomatopoda	-	-	-	-	-	-	-	-	-	24
	Order Tanaidacea	-	-	-	-	-	-	-	1	102	50
	Subphy. Crustacea (unid. larvae)	-	-	-	-	-	-	-	-	-	4
Brachiopoda		-	3	1	-	-	-	-	-	-	-
Cnidaria	Class Anthozoa	-	8	-	-	-	1	-	-	1	21
	Class Hydrozoa	-	-	3	4	-	1	13	-	5	-
	Class Scyphozoa	-	-	1	-	-	-	-	-	-	-
Echinodermata	Class Echinoidea	-	-	-	-	4	-	-	-	-	-
	Class Holothuroidea	-	9	102	60	14	5	8	35	1	-
Ectoprocta		-	8	-	-	-	-	-	-	-	-
Mollusca	Class Bivalvia	23	408	190	142	45	59	184	65	171	113
	Class Gastropoda	6,405	2,952	74	1,299	131	47	35	19	146	289
Nemertea		1	89	48	42	18	60	48	26	74	25
Phoronida		-	148	121	148	69	38	16	20	23	25
Platyhelminthes	Class Turbellaria	-	3	3	-	3	1	-	-	3	1
Porifera		-	-	-	-	-	-	1	-	-	-
Sipuncula		-	14	4	3	-	4	-	-	-	3
	Total Density (individuals/m^2)	**8,248**	**5,522**	**2,080**	**2,717**	**632**	**1,104**	**1,241**	**1,328**	**5,144**	**1,543**

Differences in infauna density for all elevations combined were statistically significant between stations (p=0.001). East basin Stations 1, 2, and 3 were similar, with mean densities of 3,205, 3,635, and 3,792 individuals/m^2, respectively, while Stations 4 and 5 had lower mean densities of 2,078 and 2,065 individuals/m^2, respectively (Figure 8-3).

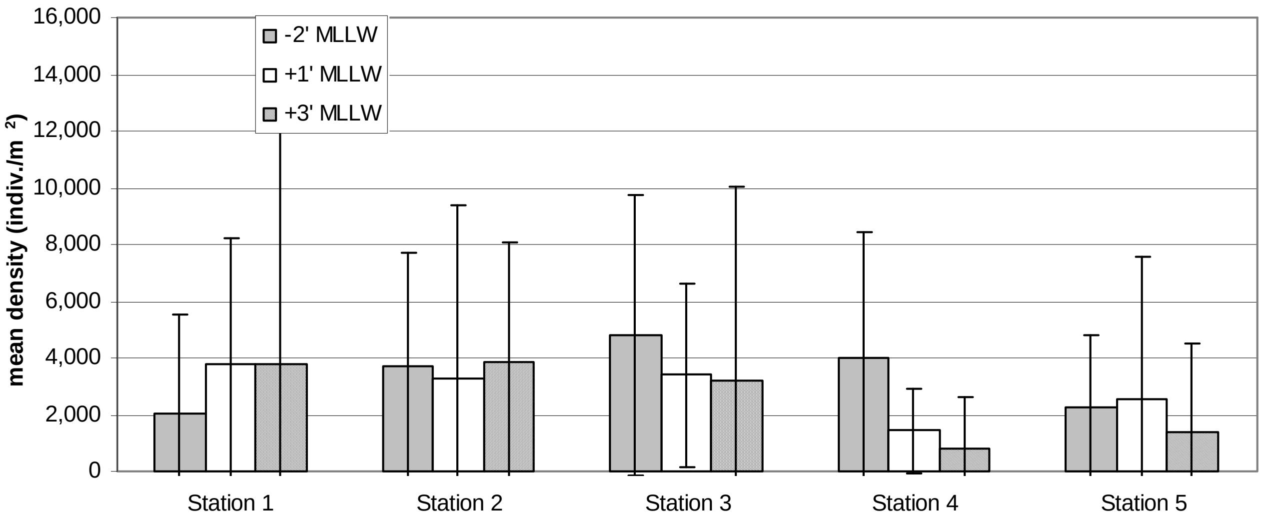


Figure 8-3. Mean density (indiv/m^2) of infauna by elevation at each sampling station ($\pm$ 1SD), n=30.

Molluscs were consistently the most abundant phylum (43% of the total), followed closely by annelids (37%), then arthropods (15%), phoronids (2%), and nemerteans (1%). The other phyla made up less than 1% of the total individuals. Density data for the three most abundant phyla are presented below.

The molluscs were composed of gastropods and bivalves, with gastropods making up over 89% of the total. Figure 8-4 presents the mean density of molluscs over time, with all stations combined. Mollusc density was found to be significantly different over time (p<0.001), with high initial densities that fell in later years. The Tukey HSD multiple comparison test found the two sampling events in 1997 (year 1) to be different from years 2, 3, 5, and 10, which were all grouped. As mentioned, this spike in the first year post-restoration mollusc density was due to the capture of the brackish water gastropod *T. imitator* in very high numbers, particularly in the east basin (Stations 1, 2, and 3). The density of this gastropod was as high as 53,853/m^2 in one replicate in January 1997. It is believed that this gastropod was well represented in the lagoon during pre-restoration sampling, but was misidentified in MBA (1988) as *Hydrobia* sp. The identification of the gastropods collected post-restoration as *T. imitator* was confirmed by R. Hershler (Smithsonian Institution) in 2009. All references to *Hydrobia* sp. in prior post-restoration project reports were in error and should be considered to be *T. imitator*. The majority of these gastropods observed in the early years of the present monitoring program were dead, suggesting that large numbers of this species persisted in the lagoon under closed conditions, but the restoration of tidal influence caused significant mortality. Only specimens that were alive at the time of capture were included in the data.

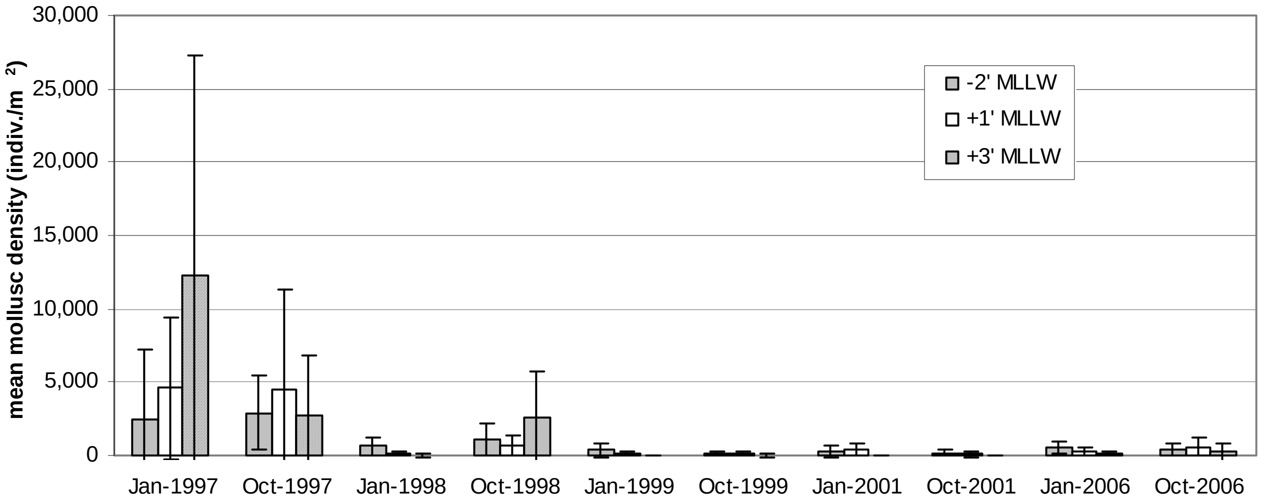


Figure 8-4. Mean density (indiv/m^2) of molluscs by elevation during each sampling event ($\pm$ 1SD), n=15.

After year 2 (1998), *T. imitator* were found in lower numbers, with molluscs such as *Conus californicus*, *Cylichna* sp., and *Nassarius* sp., all of which were also likely captured from the surface of the sample core, commonly found.

Bivalves occurred in lower numbers than gastropods. They were dense in October of the first year, represented primarily by *Tellina* sp., *Lyonsia* sp., *Laevicardium substriatum*, *Diplodonta orbella*, and *Tegula* sp., then occurred in lower but consistent densities in the following years, represented by species such as *Chione californiensis*, *Tagelus* sp., *Tellina* sp., and *L. substriatum*.

Of note was the rapid arrival of the highly invasive, non-native mussel *Musculista senhousia* in the lagoon. None were captured during the January 1997 sampling (one month post-restoration), but by the second sampling in October 1997, *M. senhousia* were observed at all five stations, ranging in density from (57 to 453 indiv/m^2). It is not known if they were present prior to October; however, the individuals captured in the cores were large enough to have been present in the lagoon for at least several months. In January 1998 (year 2), *M. senhousia* were found at Stations 2-4 in densities ranging from 57 to 340 indiv/m^2 and were absent in the October 1998 collections. In January 1999, they were captured at Stations 3 and 4 in densities ranging from 57 to 227 indiv/m^2 and were absent in the October 1999 collections. In January 2001 (year 5), they were captured at Stations 2, 3, and 4 in densities ranging from 57 to 1,019 indiv/m^2 and were absent in the October 2001 collections. In 2006 (year 10), no *M. senhousia* were captured in either the January or October infaunal collections, although some were collected in April and July 2006 in the fish sampling gear. This species was captured at all three tidal elevations over the course of the monitoring period.

The distribution of molluscs in the lagoon by tidal elevation and station is presented in Figure 8-5. Differences in mollusc density was statistically significant between stations (p=0.002) and increased from west to east, with the highest mean density at Station 1 (1,920 indiv/m^2), again due to the high *T. imitator* numbers, and the lowest mean density at Station 5 (559 indiv/m^2). The Tukey HSD multiple comparison test found Station 1 to be different from all others and grouped Stations 2 and 3, and Stations 4 and 5.

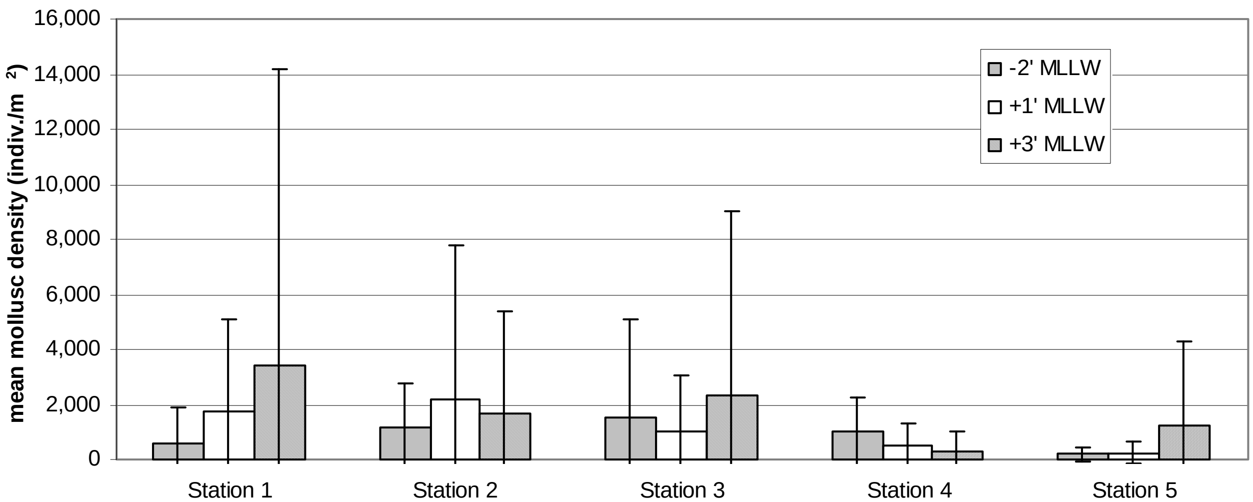
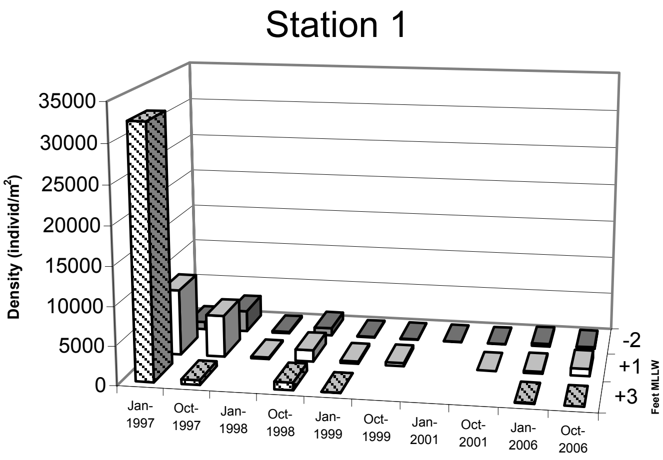
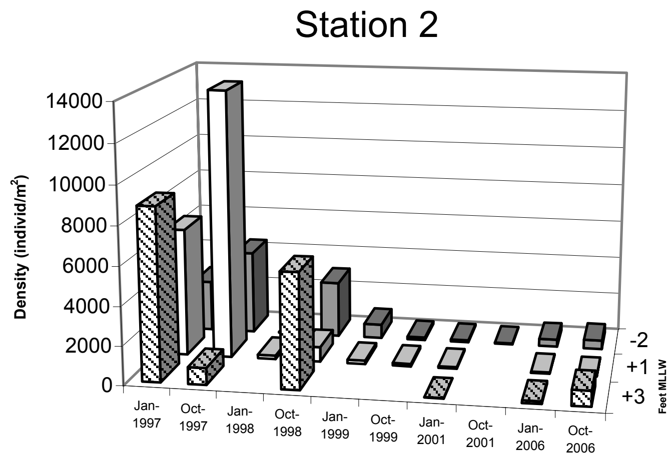
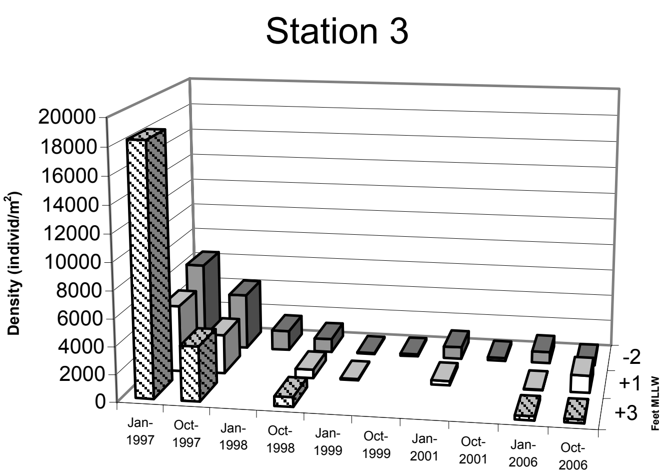


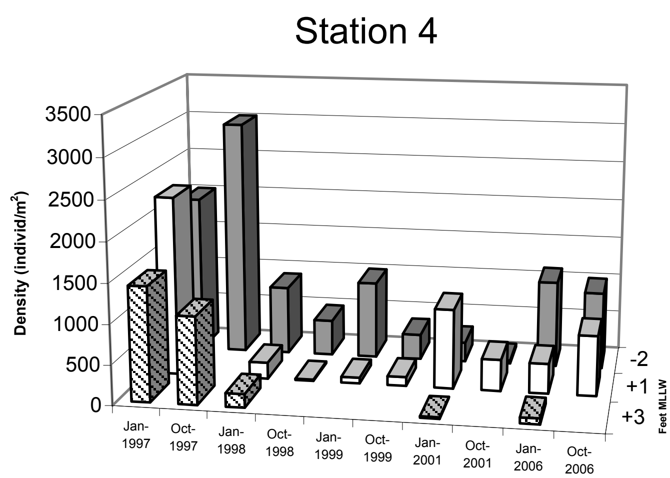
Figure 8-5. Mean density (indiv/m^2) of molluscs by elevation at each station during all sampling events ($\pm$ 1SD), n=30.

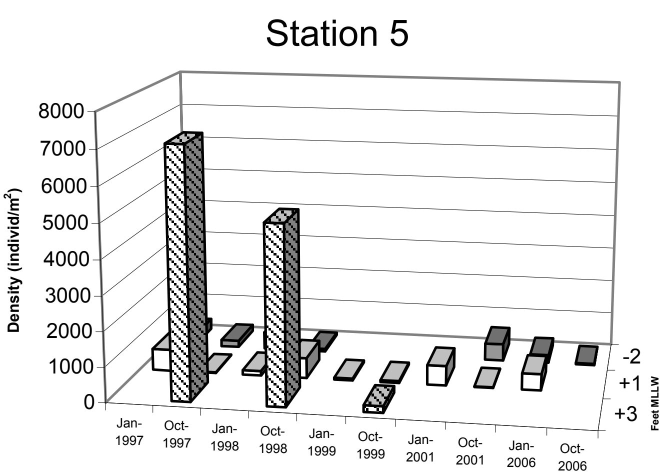
To examine trends within stations individually, Figure 8-6 presents the density of molluscs by station and elevation over time (note differing y-axis scales) and the ANOVA table for mollusc density. Elevation was found to be significant for mollusc density (p=0.019), again due to the high numbers of *T. imitator* captured at the +3-foot elevation. In later years when *T. imitator* were present in much lower numbers, molluscs were captured in higher densities at the lower +1-foot and –2-foot elevations (Figure 8-6).











ANOVA:
Mollusc density by station by elevation over time

	df	MS	F	p	Non-centrality	power
station_id	4	3.78E+07	5.42	0.002	21.68	0.95
elevation	2	3.18E+07	4.56	0.019	9.13	0.73
station_id*elevation	8	1.63E+07	2.33	0.044	18.65	0.79
Error	30	6.98E+06				
TIME	9	1.94E+08	29.32	< 0.001	263.90	1.00
TIME*station_id	36	3.27E+07	4.95	< 0.001	178.05	1.00
TIME*elevation	18	4.38E+07	6.63	< 0.001	119.30	1.00
TIME*station_id*elevation	72	2.16E+07	3.27	< 0.001	235.25	1.00
Error	270	6.60E+06				

Note variable density scales between station charts.

N
W E
S

Density (individuals/m^2) of molluscs over time by station and tidal elevation
Batiquitos Lagoon 1997-2006

Figure 8-6

Merkel & Associates, Inc.

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Nearly as abundant as molluscs were annelids, made up nearly entirely of polychaetes. The other annelids were nine oligochaetes captured in the first monitoring interval (January 1997) and four echiura, or spoon worms, captured in October 1997. Annelid densities ranged from a high of 23,725 indiv/m^2 to a low of 57 indiv/m^2, and they were occasionally completely absent from some elevations within stations. Annelid numbers were moderately high in years 1 and 2 (1997 and 1998), lower in years 3 and 5 (1999 and 2001), much higher in the beginning of year 10 (2006), and then dropped back down in the October 2006 sampling (Figure 8-7). Annelid density was found to be statistically different between sampling intervals (p= <0.001).

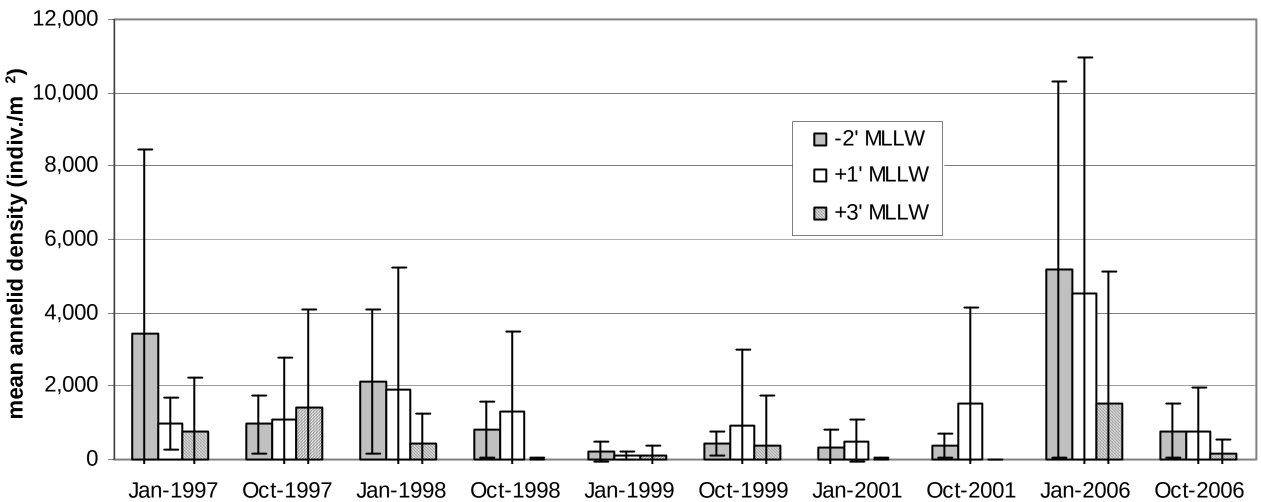


Figure 8-7. Mean density (indiv/m^2) of annelids by elevation during each sampling event ($\pm$ 1SD), n=15.

No statistically significant difference was found in annelid density between stations (p=0.070). Figure 8-8 shows the variability in annelid density between stations, with no clear trend in density across the lagoon. Mean annelid density was highest at Station 3 (1,456 indiv/m^2) and lowest at Station 1 (647 indiv/m^2). Few to no annelids were found at the +3-foot elevation at Station 5.

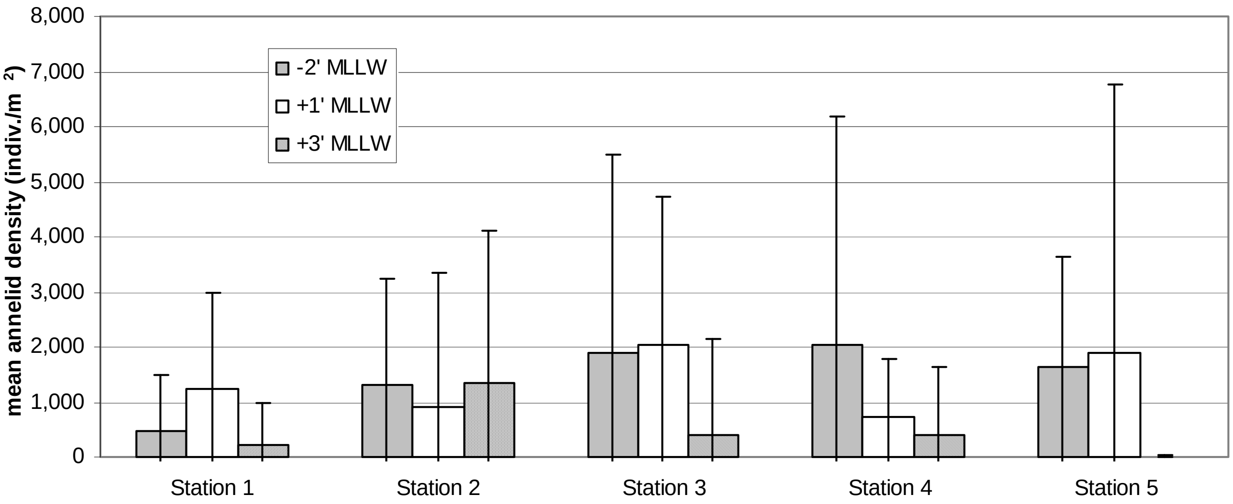
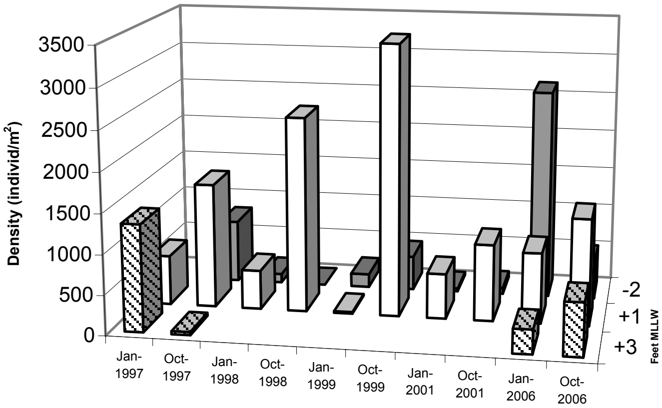


Figure 8-8. Mean density (indiv/m^2) of annelids by elevation at each station during all sampling events (+ 1SD), n=30.

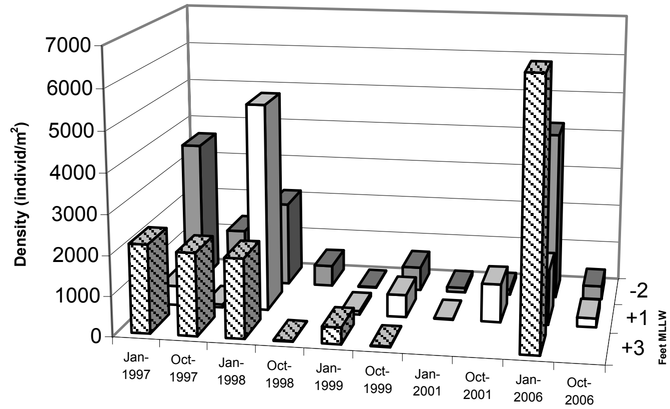
To show trends within each of the stations, Figure 8-9 presents the density of annelids by station and elevation over time (note differing y-axis scales) and the ANOVA table for annelid density. Elevation was found to be significant for annelid density (p= <0.001), with the –2-foot and +1-foot elevations having a mean annelid density of 1,471 and 1,357 indiv/m^2, respectively, while the +3-foot elevation had a mean density of 479 indiv/m^2. The Tukey HSD multiple comparison test also grouped the –2-foot and +1-foot elevations as separate from the +3-foot elevation.

The third most abundant infauna phylum, Arthropoda, was composed of amphipods (55% of all arthropods), insects (including dipterans) (19%), isopods (14%), mysids (5%), tanaids (4%), and ostracods (2%), with stomatopods, cumaceans, and decapods making up less than 1% of the total.

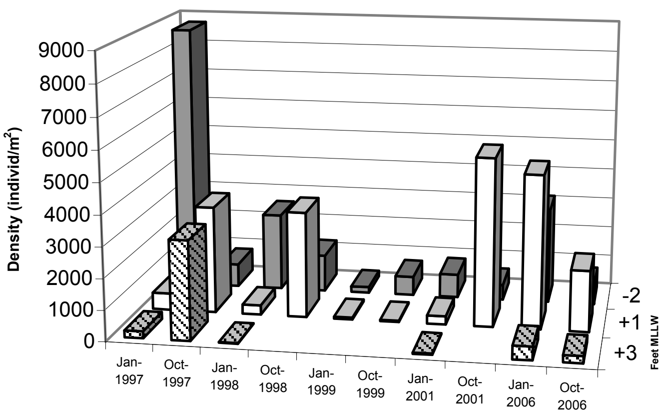
Station 1



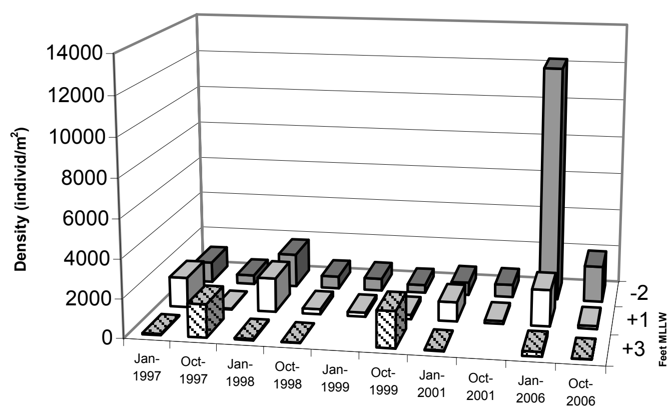
Station 2



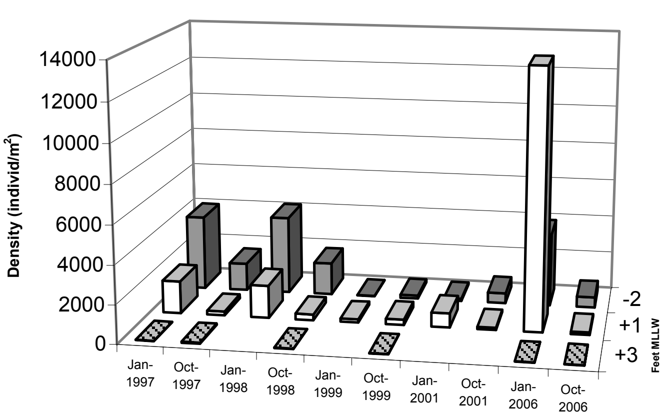
Station 3



Station 4



Station 5



ANOVA:
Annelid density by station by elevation over time

	df	MS	F	p	Non-centrality	power
station_id	4	7.80E+06	2.42	0.070	9.68	0.62
elevation	2	4.43E+07	13.75	< 0.001	27.50	1.00
station_id*elevation	8	1.09E+07	3.37	0.007	26.99	0.93
Error	30	3.22E+06				
TIME	9	5.03E+07	12.87	< 0.001	115.82	1.00
TIME*station_id	36	6.24E+06	1.60	0.021	57.48	0.99
TIME*elevation	18	8.90E+06	2.28	0.003	41.00	0.99
TIME*station_id*elevation	72	9.73E+06	2.49	< 0.001	179.24	1.00
Error	270	3.91E+06				

Note variable density scales between station charts.

N
W E
S

Density (individuals/m2) of annelids over time by station and tidal elevation
Batiquitos Lagoon 1997-2006

Figure 8-9

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Figure 8-10 presents the density of arthropods over time. Arthropods generally increased in density over time, driven primarily by increased counts of amphipods at the lower tidal elevation, as well as increases in decapods and isopods. Ostracods were present only in years 1 and 2, whereas tanaids and stomatopods were not present until the later years of the monitoring program (Table 8-1).

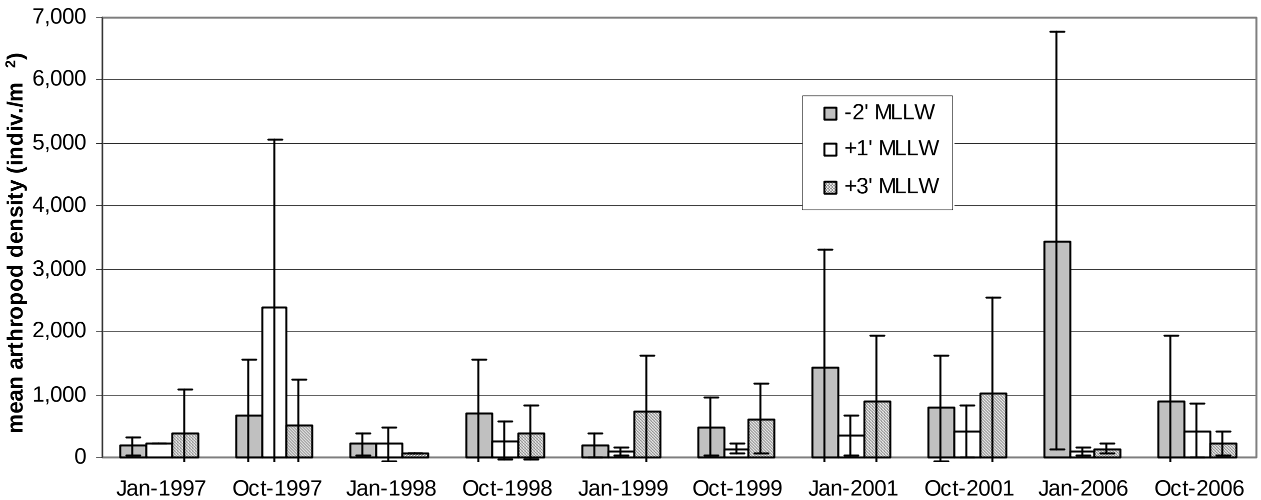


Figure 8-10. Mean density (indiv/m^2) of arthropods by elevation during each sampling event (± 1SD), n=15.

The distribution of arthropods between stations and elevations is presented in Figure 8-11. The mean arthropod density was found to be statistically significant between stations (p=<0.001). The east basin supported the highest density of arthropods (Stations 1, 2, and 3), with lower densities found at Station 4 (central basin) and Station 5 (west basin), supported by the Tukey HSD multiple comparison test which found Stations 1, 2, and 3 to be different from Stations 4 and 5.

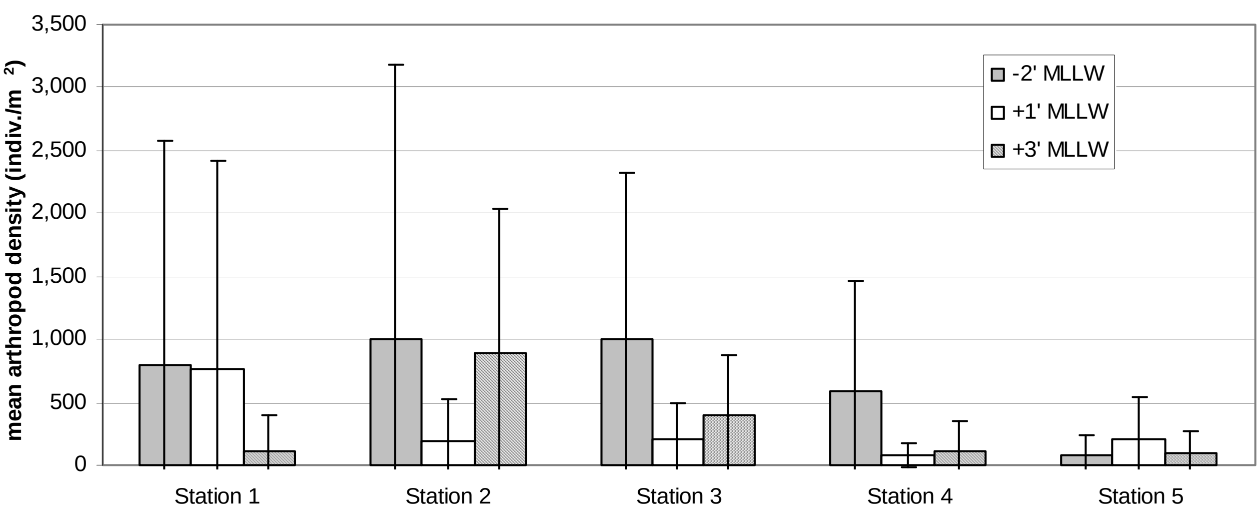


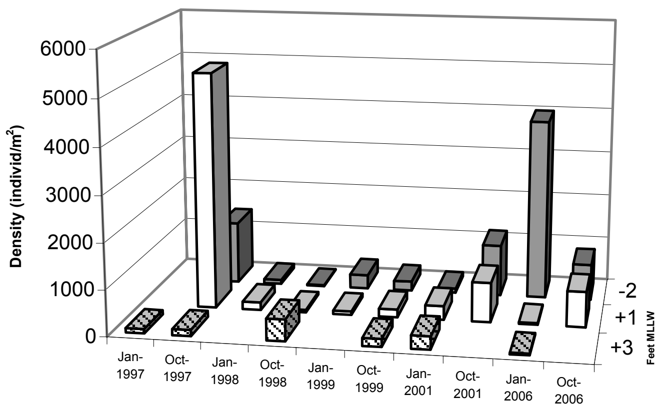
Figure 8-11. Mean density (indiv/m^2) of arthropods by elevation at each station during all sampling events (± 1SD), n=30.

Figure 8-12 presents the trends in arthropod density within stations individually (note differing y-axis scales) and the ANOVA table for arthropod density. Elevation was found to be significant for arthropod density ($p<0.001$), with the Tukey HSD multiple comparison test breaking out the +1-foot and +3-foot elevations from the –2-foot elevation. The highest mean arthropod density was at the –2-foot elevation (694 indiv/m^2) and the lowest at the +1-foot elevation (287 indiv/m^2). At the –2-foot and +1-foot elevations, the most abundant arthropods were amphipods, isopods, mysids, and tanaids; while at the +3-foot elevation, insects were the most commonly captured arthropods (62% of all arthropods), followed by amphipods and ostracods in lower numbers.

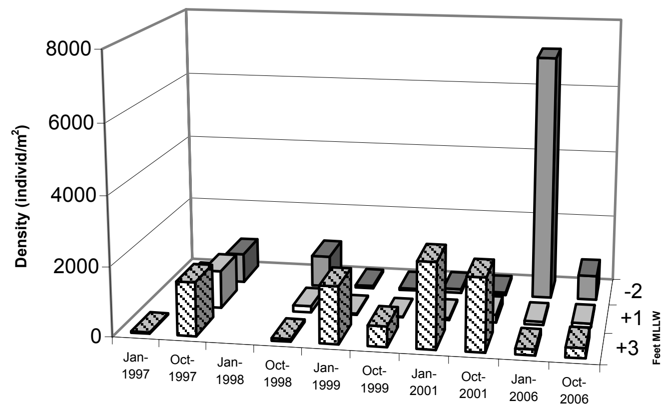
<u>Biomass</u>

The biomass of the 12 phyla collected over the 10-year post-restoration monitoring period is presented in Table 8-2 and in Figure 8-13. The lowest mean biomass was found in January 1999 (year 2) (2.3 g/m^2), and the highest during the last sampling event in October 2006 (92.4 g/m^2) when several large molluscs were captured.

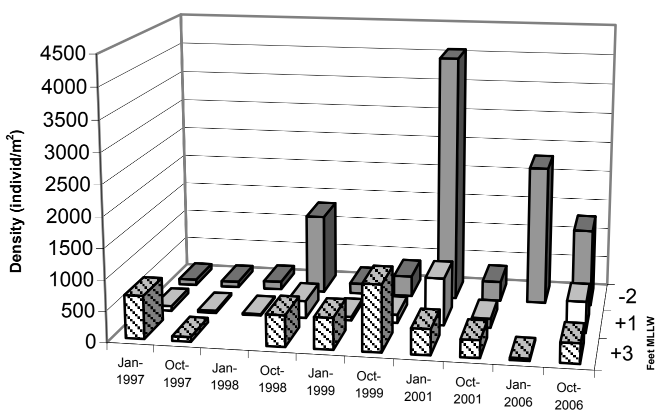
Station 1



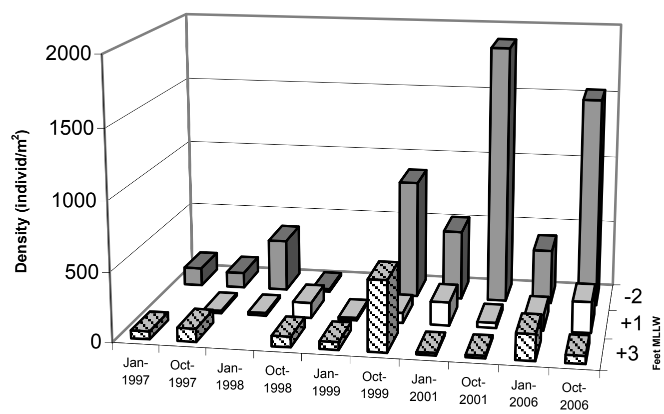
Station 2



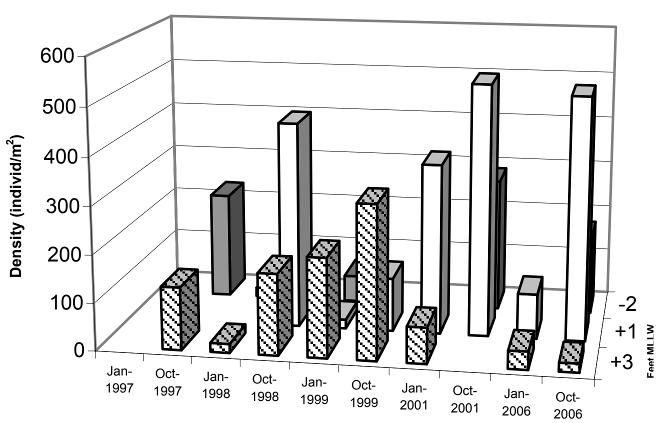
Station 3



Station 4



Station 5



ANOVA:
Arthropod density by station by elevation over time

	df	MS	F	p	Non-centrality	power
station_id	4	4.88E+06	13.38	< 0.001	53.52	1.00
elevation	2	7.64E+06	20.96	< 0.001	41.93	1.00
station_id*elevation	8	2.61E+06	7.17	< 0.001	57.40	1.00
Error	30	3.64E+05				
TIME	9	3.91E+06	10.44	< 0.001	93.99	1.00
TIME*station_id	36	2.06E+06	5.50	< 0.001	197.82	1.00
TIME*elevation	18	4.18E+06	11.18	< 0.001	201.20	1.00
TIME*station_id*elevation	72	2.01E+06	5.37	< 0.001	386.59	1.00
Error	270	3.74E+05				

Note variable density scales between station charts.

N
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Density (individuals/m²) of arthropods over time by station and tidal elevation
Batiquitos Lagoon 1997-2006

Figure 8-12

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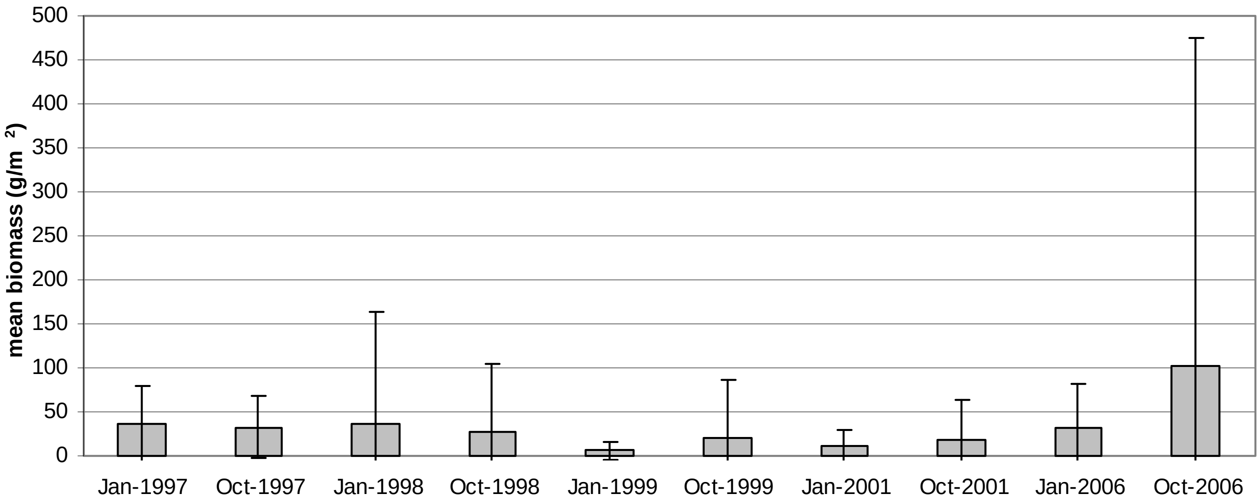

Figure 8-13. Mean biomass (g/m^2) of infauna during each sampling event (+ 1SD), n=45.

Biomass was dominated by molluscs (78% of the total biomass). Most molluscs have shells, resulting in a greater relative contribution to biomass relative to the other non-shelled infauna. Annelids made up 13%, arthropods were 4%, and phoronids were 1% of the total biomass, with the other phyla composing less than 1%. The three top ranking phyla are presented separately below.

Mollusc biomass ranged between a mean of 2.3 and 31.0 g/m^2 during each of the first nine sampling events then increased to a mean of 92.4 g/m^2 in October 2006 (Figure 8-14). This resulted from the capture of several large *Protothaca staminea*, *C. californicus*, *L. substriatum*, *Chione* sp., *Tagelus* sp., *Tellina* sp., and *Argopecten ventricosus* in October 2006. There was a statistically significant difference in mollusc biomass between sampling events ($p<0.001$), with the Tukey HSD multiple comparison test finding October 2006 to be different from the nine prior events.

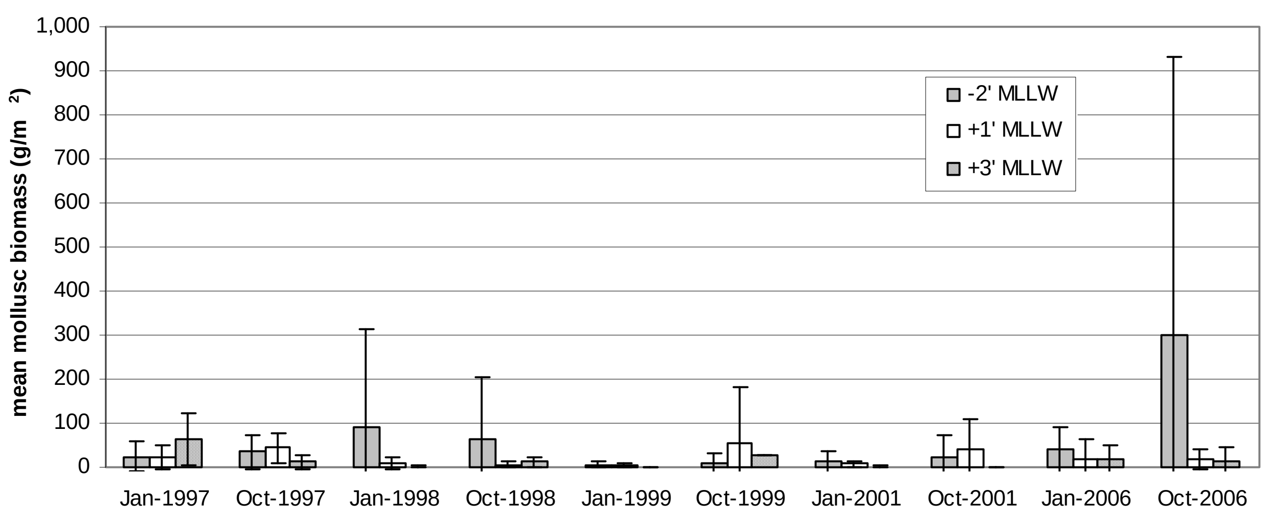

Figure 8-14. Mean biomass (g/m^2) of molluscs during each sampling event (+ 1SD), n=15.

Table 8-2. Infauna biomass (g/m^2) by phylum at all stations at Batiquitos Lagoon (1997-2006).

	Monitoring Period									
	Year 1		Year 2		Year 3		Year 5		Year 10	
Phylum	**Jan-1997**	**Oct-1997**	**Jan-1998**	**Oct-1998**	**Jan-1999**	**Oct-1999**	**Jan-2001**	**Oct-2001**	**Jan-2006**	**Oct-2006**
Phylum Annelida	4.5670	3.4394	3.6629	1.5469	1.2348	2.1153	4.4389	1.6412	9.1953	9.0642
Phylum Arthropoda	0.1129	0.5738	0.1073	0.4877	0.3803	1.0234	1.3765	5.6381	2.0169	1.1616
Phylum Brachiopoda	-	0.0975	0.0003	-	-	-	-	-	-	-
Phylum Cnidaria	-	0.0987	0.0031	0.0047	-	0.0227	0.0219	-	0.0208	0.0498
Phylum Echinodermata	-	0.0575	1.8079	0.5422	0.2883	0.0169	0.1388	1.1828	0.0047	-
Phylum Ectoprocta	-	0.0082	-	-	-	-	-	-	-	-
Phylum Mollusca	30.9076	25.2054	29.3694	22.2091	2.3395	15.2678	3.8928	10.4462	21.0459	92.3812
Phylum Nemertea	-	0.6996	0.3190	0.1760	0.2075	0.5978	0.7074	0.0939	0.4535	0.1996
Phylum Phoronida	-	2.2601	1.6181	3.1034	1.2963	0.5567	0.4921	0.2265	0.0279	0.2177
Phylum Platyhelminthes	-	0.0013	0.0239	-	0.0058	0.0059	-	-	0.0444	0.0021
Phylum Porifera	-	-	-	-	-	-	0.0020	-	-	-
Phylum Sipuncula	-	0.1604	0.0109	0.0161	-	0.0205	-	-	-	0.0184
Total Biomass (g/m^2)	**35.5875**	**32.6019**	**36.9229**	**28.0862**	**5.7525**	**19.6269**	**11.0705**	**19.2288**	**32.8094**	**103.0945**

There was a statistically significant difference in mollusc biomass between stations (p=0.007) and elevations (p<0.001) (Figure 8-15). Mean mollusc biomass was lowest at Station 2 (12.5 g/m^2) and highest at Station 4 (53.6 g/m^2). Mean mollusc biomass for all stations combined was highest at the –2-foot elevation (52.1 g/m^2), lowest at the +3-foot elevation (8.7 g/m^2), and moderate (15.1 g/m^2) at the +1-foot elevation. The Tukey HSD multiple comparison test found the –2-foot elevation to be different from the two higher elevations, which it grouped together.

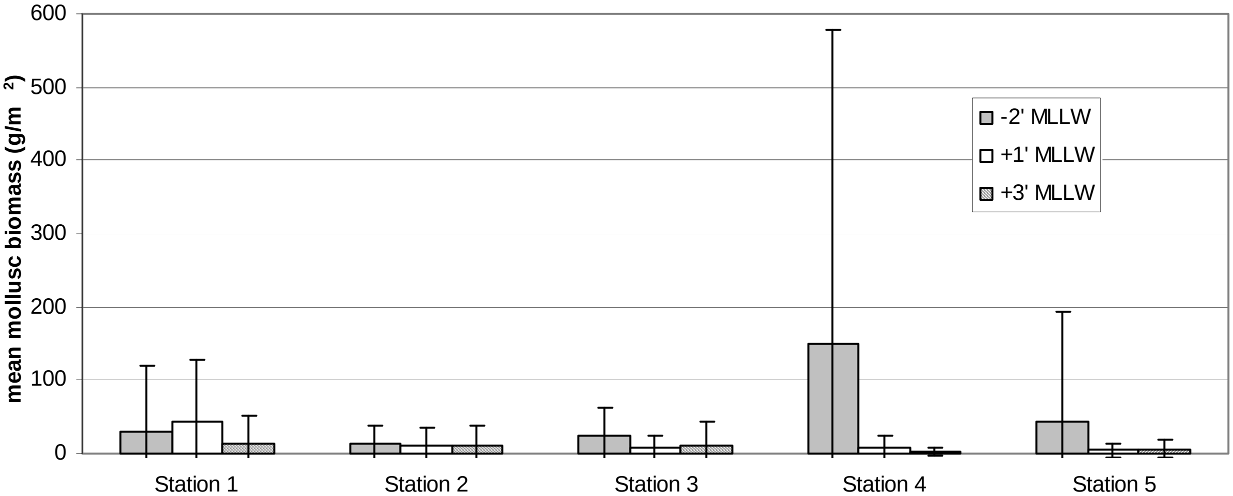

Figure 8-15. Mean biomass (g/m^2) of molluscs by elevation at each station during all sampling events (+ 1SD), n=30.

Annelid biomass ranged between a mean of 1.2 and 4.6 g/m^2 during each of the first eight sampling events (years 1, 2, 3, and 5) then increased to a mean of over 9.0 in both of the year 10 sampling events (2006) (Figure 8-16). The difference in annelid biomass was statistically significant between sampling events (p<0.001), with the Tukey HSD multiple comparison test finding the 2006 events to be different from the prior four years. Although the density of annelids was not high in October 2006 (Figure 8-7), notably large polychaetes were found at the –2-foot elevation, contributing to the high biomass during that sampling event.

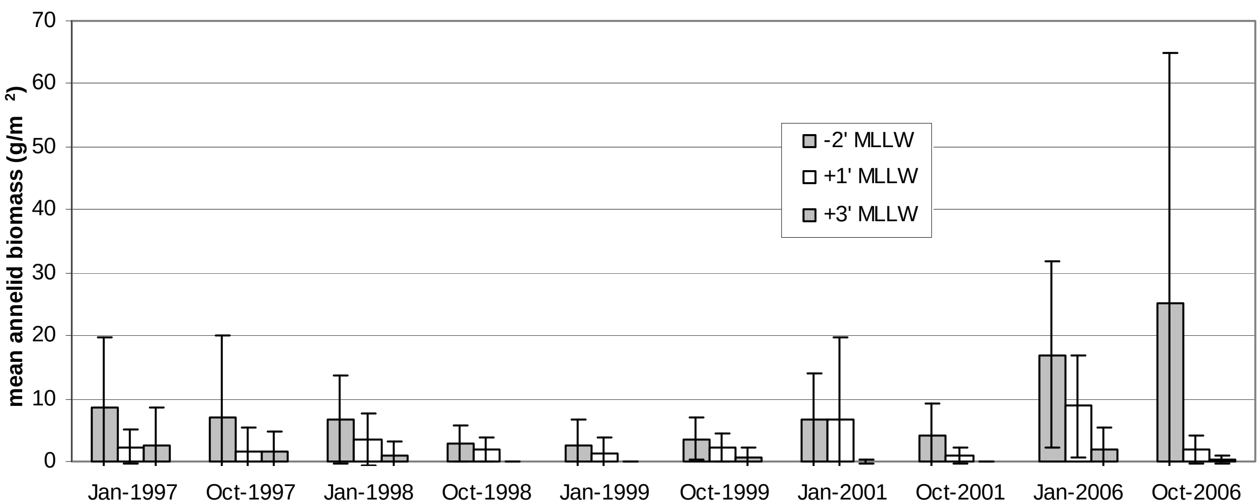

Figure 8-16. Mean biomass (g/m^2) of annelids during each sampling event (+ 1SD), n=15.

Annelid biomass was highest in the central and west basins (Stations 4 and 5) and decreased from west to east in the east basin (Figure 8-17). There was a statistically significant difference in annelid biomass between stations (p<0.001), with the mean biomass ranging from 1.3 g/m^2 (Station 1) to 7.7 g/m^2 (Station 4). The Tukey HSD multiple comparison test identified Station 4 as different from the other stations. The difference in annelid biomass was statistically significant between elevations (p<0.001), highest at the –2-foot elevation and lowest at the +3-foot elevation. The Tukey HSD multiple comparison test found all elevations to be different from each other.

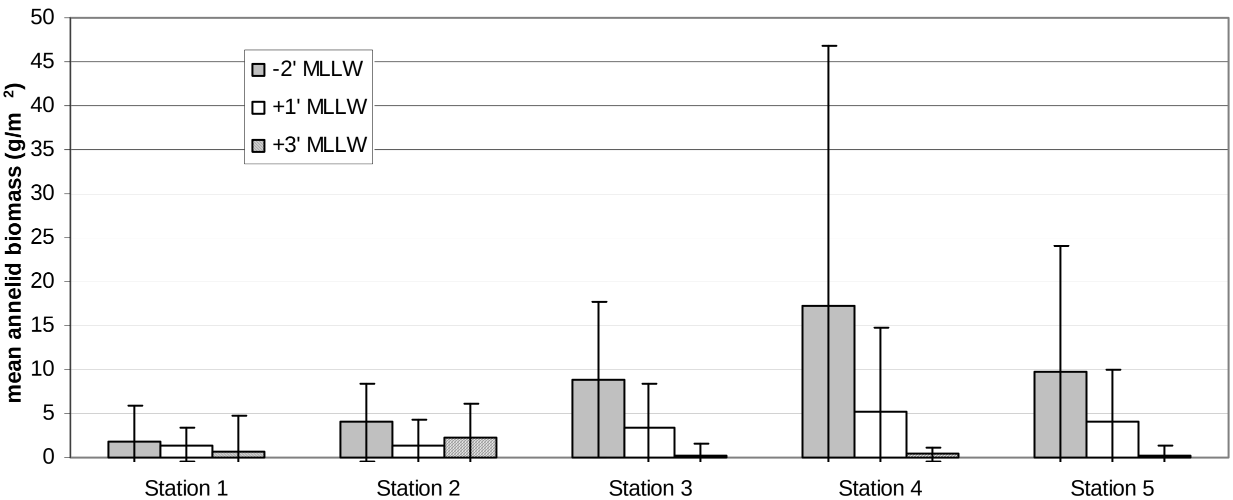

Figure 8-17. Mean biomass (g/m^2) of annelids by elevation at each station during all sampling events (+ 1SD), n=30.

There was a statistically significant difference in arthropod biomass between sampling events (p=0.002). Arthropod biomass was highest in October 2001 (5.6 g/m^2), when single *Neotrypaia californiensis* and *Hemigrapsus nudis* were captured, contributing more mass than other arthropods typically captured (Figure 8-18).

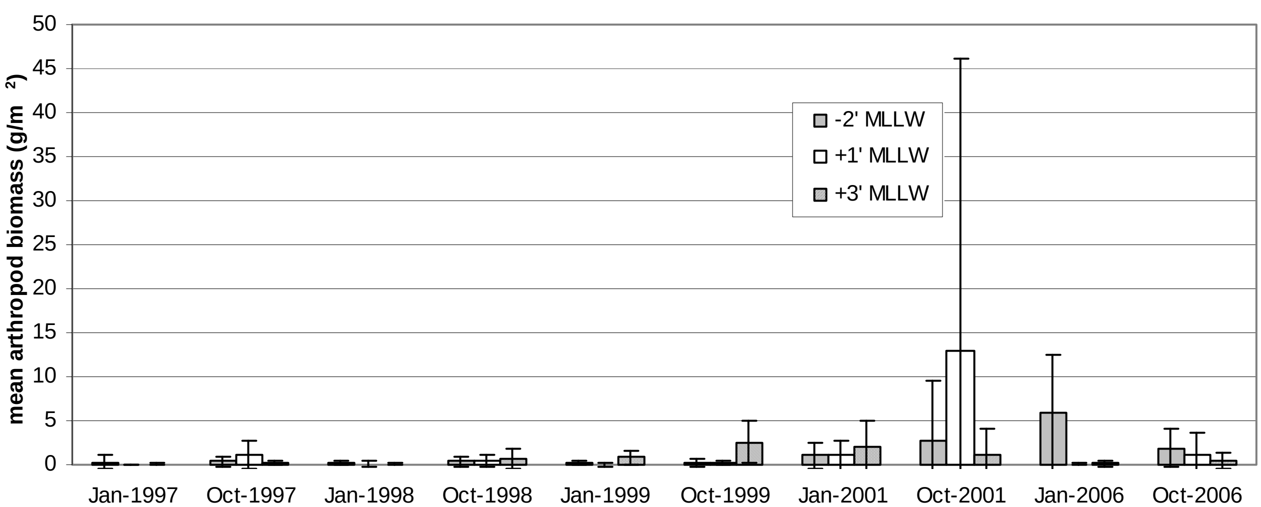

Figure 8-18. Mean biomass (g/m^2) of arthropods during each sampling event (+ 1SD), n=15.

There was no statistically significant difference in arthropod biomass between stations (p=0.851) and elevations (p=0.470) (Figure 8-19).

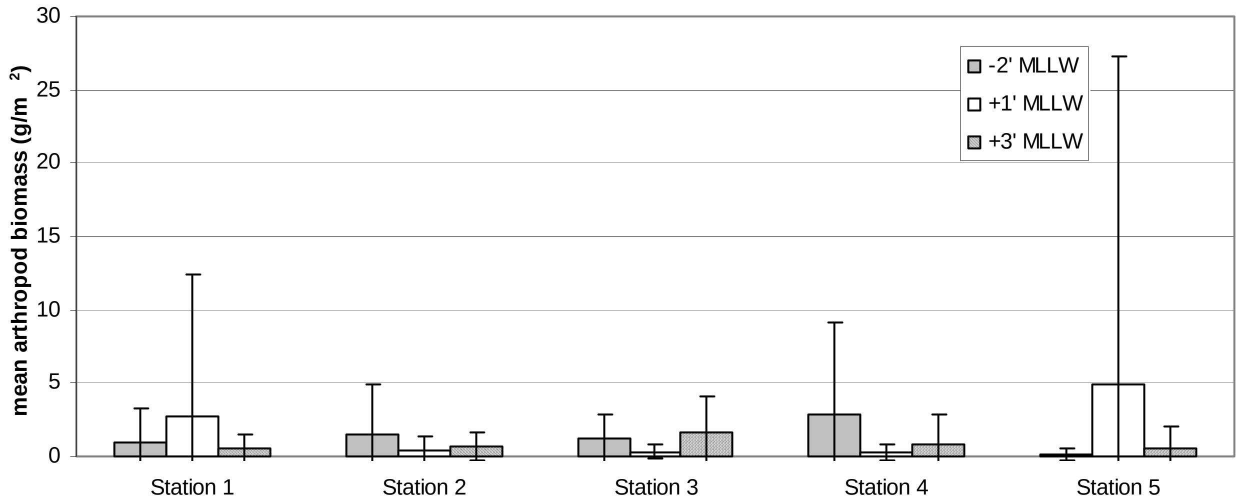

Figure 8-19. Mean biomass (g/m^2) of arthropods by elevation at each station during all sampling events (+ 1SD), n=30.

8.2.2 Epifauna

Epibenthic surveys were completed during the January and October benthic sampling intervals and quarterly to document by-catch associated with fish surveys. This section includes the results of all of these data collection efforts.

The focused epibenthic investigations provided limited information concerning the distribution and abundance of macroalgae and invertebrates inhabiting the intertidal and shallow subtidal areas. A summary of the organisms found in the quadrat sampling is provided in Table 8-3. The results are broken out by tidal elevation, with all five stations (three replicates each) combined.

A total of only 58 animals were recorded in the 10-year monitoring period. *Bulla gouldiana* was the most abundant organism consistently identified, frequently occurring at the lower tidal elevations at Stations 3, 4, and 5. The –2-foot elevation generally had the most organisms, including *Navanax inermis*, *A. ventricosus*, *Nassarius tegula*, *Olivella biplicata*, and *Hippolyte californiensis* (Table 8-3). At the +1-foot elevation, organisms included the same as above, plus *Cerithidea californica*, *Pachygrapsus crassipes*, and others. The +3-foot elevation had the least number of organisms, with *C. californica* the most abundant.

Trends in abundance over time and elevation in the quadrat surveys were very difficult to detect due to the patchy occurrence of the organisms, the very small sample size, and the difficulty in ascertaining the true tidal elevation. However, the greatest abundance and diversity was seen in year 5 (2001).

The most common vegetative cover within the 1-m^2 sampling quadrat at the –2-foot elevation was initially *Ulva* spp. and *Enteromorpha* spp. Subsequently, *Z. marina* became established at the –2-foot sampling areas at Stations 2, 3, and 4. At the +1-foot elevation, vegetation was a mix of filamentous green algae (*Enteromorpha* and *Chaetomorpha*), with some *Ulva* as well. In year 10, *Z. marina* occurred at the +1-foot elevation at Station 2, indicative of the increased inundation periods at the higher elevations in the later years of the monitoring program. At the +3-foot elevations, in addition to the green algaes were vascular plants including *Spartina foliosa, Sarcocornia pacifica, Distichlis spicata, Jaumea carnosa*, and others (Table 8-3).

Epibenthic invertebrates captured in the fish sampling gear were more diverse than in the quadrat sampling and included 1 cephalopod (*Octopus bimaculatus*), 22 species of gastropod, 17 bivalves, 20 crustaceans, 4 echinoids, 1 asteroid, 2 anthozoans, and the non-native bryozoan *Zoobotryon verticillatum* (Table 8-4). Detailed species counts by station are included in Appendix A8-1. Over 15,000 individuals were captured, providing a larger data set to examine for spatial and temporal trends.

Station 4 was the most diverse, with considerably more gastropod species than other stations, while the other stations all had roughly the same number of species. Similar to the 1-m^2 quadrat sampling, diversity and abundance were highest in July and October 2001, with as many as 23 species captured at Station 4. The most consistently present molluscs were the gastropods *B. gouldiana, N. inermis, N. tegula,* and the bivalve *A. ventricosus*. Among crustaceans, *Hemigrapsus oregonensis* and the shrimp *H. californiensis* were most common. Swimming crabs were captured periodically: *Callinectes arcuatus* and *Portunus xantusii*. Sand dollar, three species of sea urchin, and a sea star were occasionally captured as well (Appendix A8-2). The invasive mussel *M. senhousia* was captured at all stations except Station 1, though it was documented at all stations in the infaunal sampling reported above.

Epifauna were consistently most abundant at Station 4 (Figure 8-20) due to the regular capture of hundreds of *H. californiensis* shrimp and *B. gouldiana* (Appendix A8-1). Similarly high mean abundance at Station 5 was accounted for by high numbers of *B. gouldiana, N. tegula* and *A. ventricosus*. Station 3 was dominated by *B. gouldiana* and *A. ventricosus.* Stations 1 and 2 were dominated by gastropods *B. gouldiana, C. californica, N. tegula, and N. inermis. Argopecten ventricosus* was only captured in small numbers at Stations 1 and 2.

Table 8-3. Epibenthic organisms in 1-m^2 quadrat by elevation, with all replicates and stations combined (1997-2006).

+3 feet MLLW Elevation	Jan-97	Oct-97	Jan-98	Oct-98	Jan-99	Oct-99	Jan-01	Oct-01	Jan-06	Oct-06
Vegetation (% cover)										
Algae										
Ulva spp.			0-25%	0-25%						
Enteromorpha/Chaetomorpha mix			0-10%	0-10%	0-75%	0-50%	0-100%	0-10%	0-20%	
Vascular Plants										
Sarcocornia pacifica							0-50%	0-75%	0-20%	0-25%
Arthrocnemum subterminale								0-1%		
Distichlis spicata							0-50%	0-100%	0-10%	
Jaumea carnosa									0-20%	0-25%
Carpobrotus edulis										0-25%
Spartina foliosa								0-5%	0-100%	0-25%
Invertebrates (count)										
Gastropods										
Bulla gouldiana									1	
Cerithidea californica									16	62
Bivalves										
Argopecten ventricosus					1	1				
Crustaceans										
Calinectes arcuatus				1						
Pachygrapsus crassipes								5		
Total Number of Invertebrate Species at +3 feet MLLW	0	0	1	1	1	1	0	1	2	1

+1 foot MLLW Elevation	Jan-97	Oct-97	Jan-98	Oct-98	Jan-99	Oct-99	Jan-01	Oct-01	Jan-06	Oct-06
Vegetation (% cover)										
Algae										
Ulva spp.		0-60%								0-30%
Enteromorpha/Chaetomorpha mix		0-20%	0-100%	0-100%	0-100%	0-80%	0-100%	0-70%	0-10%	
Vascular Plants										
Zostera marina										0-70%
Invertebrates (count)										
Gastropods										
Bulla gouldiana		10	77	155	119	14	22	1		
Cerithidea californica									5	2
Navanax inermis					1		4			
Nassarius sp.							7			
Nassarius tegula							1	2		
Bivalves										
Argopecten ventricosus						1	1	1		
Laevicardium substriatum							3			
Chione californiensis							2			
Crustaceans										
Cancer antennarius							1			
Hemigrapsis oregonensis		1								
Hippolyte californiensis							10			
Pachygrapsus crassipes		1								2
Pagurus hirsutiusculus							2			
Echinoids										
Dendraster excentricus							1			
Total Number of Invertebrate Species at +1 foot MLLW	0	3	1	1	2	2	11	3	1	2

-2 feet MLLW Elevation	Jan-97	Oct-97	Jan-98	Oct-98	Jan-99	Oct-99	Jan-01	Oct-01	Jan-06	Oct-06
Vegetation (% cover)										
Algae										
Ulva spp.		0-90%	0-100%						0-100%	
Enteromorpha spp.		0-15%								
Colpomenia sp.					0-2%					
Vascular Plants										
Zostera marina								0-100%	0-50%	0-100%
Invertebrates (count)										
Gastropods										
Bulla gouldiana		63	216	4	32	10	1			
Navanax inermis					1	1	1			
Nassarius tegula			1	5	1					
Olivella biplicata							6			
Tagelus californianus						1				
Turridae sp.							211			
Bivalves										
Argopecten ventricosus			2				23			
Laevicardium substriatum				2						
Crustaceans										
Cancer antennarius							1			
Cycloxanthops novemdentatus							1			
Megalops larva			1							
Hippolyte californiensis							41			
Pagurus sp.							3			
Bryozoans										
Zoobotryon verticillatum				0-25%						
Total Number of Invertebrate Species at -2 feet MLLW	0	1	4	4	3	3	9	0	0	0

Table 8-4. Epibenthic organisms captured during fish sampling with all replicates and stations combined (1997-2006).

Taxa	1997*	1998*	Jul-99	Oct-99	Jan-01	Apr-01	Jul-01 day&night	Oct-01	Jan-06	Apr-06	Jul-06 day&night	Oct-06
Cephalopods												
Octopus bimaculatus					X		X					
Gastropods												
Aplysia californica		X	X	X	X	X		X				
Alia carinata							X	X	X		X	X
Bulla gouldiana	X	X	X	X	X	X	X	X	X	X	X	X
Conus califonicus					X	X	X	X	X	X	X	X
Cerithidea californica		X	X						X	X	X	X
Crepidula fornicata											X	X
Crucibulum spinosum									X	X		
Fusinus luteopictus								X				
Lithopoma undosa							X					
Littorina planaxi			X				X					
Kelletia kelletii									X			
Hermissenda crassicornis		X										
Tagelus californianus		X		X								
Nassarius sp.		X						X				X
Nassarius fossatus								X				
Nassarius tegula			X	X	X	X	X	X	X	X	X	X
Navanax inermis	X		X	X	X	X	X	X	X	X	X	X
Notoacmea sp.								X				
Notoacmea depicta								X				
Pesula pediculos									X			
Polinices sp.									X			
Tegula aureotincta								X	X		X	
Bivalves												
Argopecten ventricosus	X	X	X	X	X	X	X	X	X	X	X	X
Ostrea lurida							X	X				
Chione fluctifraga								X				
Chione sp.								X				
Chione californiensis					X	X				X	X	
Cirolana harfordi								X				
Musculista senhousei **		X	X	X	X	X			X	X	X	
Chione undatella					X		X	X				
Laevicardium substriatum		X		X		X	X	X	X		X	X
Tagelus californianus										X		
Tagelus subteres								X				
Macoma nasuta								X				
Mytilus galloprovincialis			X	X							X	X
Mytilus californianus			X		X	X						
Mitrella carinata												
Cancer productus								X				
*Tapes japonica***												X
Pagurus hirsutiusculus								X				
Crustaceans												
Portunus xantusii xantusii	X				X			X				
Cancer antennarius					X	X	X					
Callinectes arcuatus		X	X								X	
Cycloxanthops novemdentatus					X							
Crangon fransiscorum									X			
Epialtoides hiltoni			X									
Hemigrapsus sp.	X	X									X	X
Hemigrapsus oregonensis			X		X	X	X	X			X	X
Hemigrapsus nudus								X				
Cancer jordani					X	X						
Isocheles pilosus							X					

Table 8-4. Epibenthic organisms captured during fish sampling with all replicates and stations combined (cont'd).

Taxa	1997*	1998*	Jul-99	Oct-99	Jan-01	Apr-01	Jul-01 day&night	Oct-01	Jan-06	Apr-06	Jul-06 day&night	Oct-06
Lysmata californica							X					
Lophopanopeus frontalis							X	X				
Loxorhynchus grandis					X							
Hippolyte californiensis					X	X	X	X			X	X
Palaemon macrodactylus			X						X		X	X
Pachygrapsus crassipes	X	X	X			X	X			X		X
Pagurus hirsutiusculus					X			X	X			
Paguristes ulreyi												X
Pugettia producta					X							X
Uca sp.		X										
<u>Echinoids</u>												
Lytechinus anamesus				X	X		X	X		X		
Strongylocentrotus purpuratus					X	X	X					
Strongylocentrotus franciscanus							X					
Dendraster excentricus			X	X			X	X				
<u>Asteroids</u>												
Astropecten armatus				X								
<u>Turbellerians (Flat Worms)</u>												
Notoplana acticola								X				
<u>Lophophorata</u>												
*Zoobotryon verticillatum***		X									X	
<u>Anthozoa</u>												
Epiactis prolifera									X			
Metridium sp.									X			
TOTAL	6	14	16	12	22	16	23	32	19	12	16	19

* Invertebrates captured in the fishing gear were noted only as present or absent in 1997 and 1998. Quarterly enumeration began in July 1999.

** Non-native species

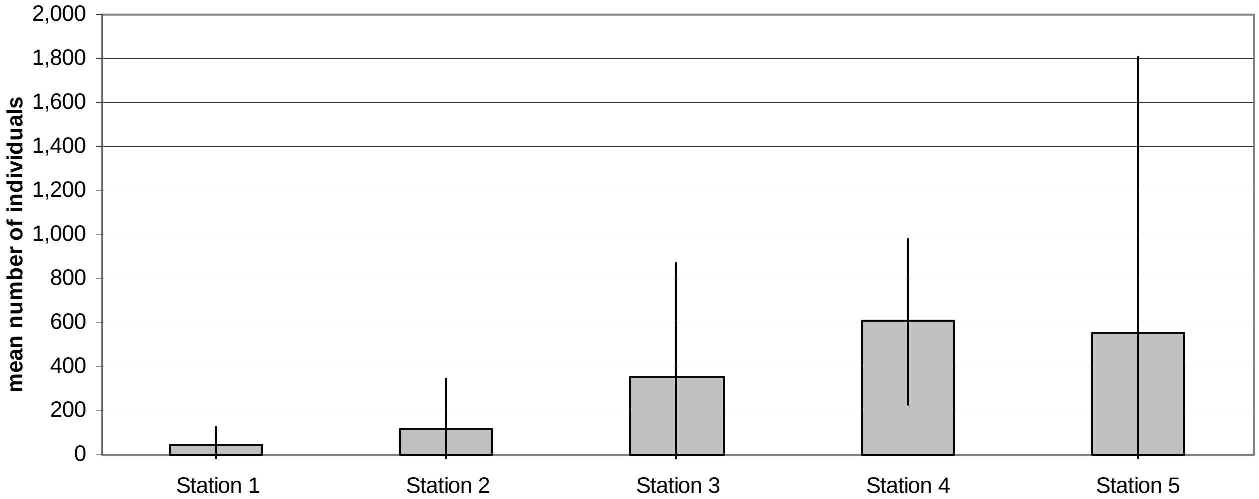

Figure 8-20. Mean number of epibenthic invertebrates captured during fish surveys (+ 1SD), n=11.

8.2.3 Sediment Grain Size

The resulting of the grain size analysis of sediment samples collected at each of the infauna sampling locations is included in Appendix A8-2.

8.3 DISCUSSION

Patchiness is an established characteristic of benthic invertebrate communities. Most marine invertebrates are rapid colonizers, with community composition being driven by sediment characteristics and the frequency and spatial scale of disturbances (Thrush et al. 1996, Levin and Talley 2002). Variability in invertebrate abundance and biomass through time and across stations can be attributed to an uneven distribution of food or other resources, subtle substrate differences, or localized environmental impacts within a community.

Within Batiquitos Lagoon, these conditions were exacerbated post-restoration by several additional factors, including radical changes in the physical environment (water and sediment) when tidal influence was restored, lack of established biotic controls and community structuring influences, and unstable and highly patchy sediment environments. In addition, the lagoon experienced a strong El Niño, a gradual shift in tidal prism, and changes in effective inundation frequency resulting from tidal muting (see Chapter 2). To add to the complexity of data interpretation, many of the changes experienced during the 10 years since lagoon mouth opening were not clearly directional and were potentially affected by seasonal events such as a heavy fluvial sediment loading during the winter and spring of 1998. The unique sediment characteristics generated within the ridged dredge scars also contributed to the patchy environment of the lower intertidal and subtidal elevations within the lagoon, with fine silty sediment in scar troughs and consolidated clay sediment dominating the trough ridges. Finally, the monitoring program was not conducted at a frequency capable of segregating seasonal patterns from interannual variability or with enough replication to detect directional trends amidst the high variability within station elevations.

Despite high variability between and within stations and sampling years, the benthic and epibenthic monitoring program clearly illustrated the transition of Batiquitos Lagoon from a closed lagoon subject to extreme salinity and temperature regimes to an open tidal lagoon. Historic data collected at Batiquitos Lagoon suggest that the lagoon was rarely open to tidal influence and contained few of the marine invertebrates associated with nearby lagoons under tidal influence (City of Carlsbad and U.S. Army Corps of Engineers 1990).

Prior to restoration, the lagoon was known to support seven phyla comprised of 36 taxa of invertebrates, including acoelomates, nematodes, polychaetes, oligochaetes, turbellarians, nemerteans, gastropods, pelecypods, insects, other arthropods, and bryozoans (MBA 1988, reviewed in City of Carlsbad and U.S. Army Corps of Engineers 1990). MBA (1988) and MEC (1988) found Batiquitos Lagoon to be dominated by the ostracod *Cyprideis beaconensis*, midge larvae (*Metriocnemus* sp.), and a gastropod "*Hydrobia* sp.", believed to actually have been *Tryonia imitator*. *Cyprideis beaconensis* is a wide-ranging species believed to be capable of existing across a range of salinities from brackish to hypersaline (Haury 1988, MBA 1988). *Cyprideis beaconensis* was typically found in the more saline waters west of Interstate 5 (I-5), whereas *Metriocnemus* sp. and "*Hydrobia* sp." (*T. imitator*) were more common in eastern habitats with greater freshwater influence (MBA 1988, MEC 1988).

During the sampling periods immediately following the restoration of Batiquitos Lagoon, samples were dominated in biomass and density by *T. imitator*. Although *T. imitator* is an epifaunal snail, it was enumerated as part of the infaunal catch as it was collected in high numbers within sample cores. This treatment is similar to prior surveys that did not separate epifauna from infaunal data (MBA 1988, MEC 1988). By the end of the second year, *T. imitator* had been largely replaced by other snail species common to local marine bays and estuaries such as *C. californicus*, *Cylichna* sp., and *Nassarius* spp. The densities of these other species were much lower but more stable than the initial densities of *T. imitator*.

In addition to the evolving gastropod community, the transition of the lagoon was marked by the rapid colonization by polychaetes and bivalves and the loss of insects and insect larvae. These observations reflect the expected change of the system to resemble other nearby estuarine systems. Agua Hedionda Lagoon, San Dieguito Lagoon, and Tijuana River Estuary all support communities dominated by polychaetes, gastropods, bivalves, and crustaceans (City of Carlsbad and U.S. Army Corps of Engineers 1990). Ultimately, Batiquitos Lagoon was dominated in both density and biomass by molluscs (gastropods and bivalves), annelids (primarily polychaetes), and arthropods (primarily crustaceans), respectively.

Across the lagoon, there were trends with regard to the presence of invertebrates. The two westernmost stations contained 71% fewer invertebrates on average relative to the three easternmost stations in the east basin. This is in opposition to the trends observed prior to the restoration (MBA 1988). The MBA (1988) study found that invertebrate density decreased moving east across the basins with 12,917, 12,154, and 4,225 indiv/m^2 in the west, central, and east basins, respectively. The relative differences in the pre- and post-restoration observations are likely related to the physical environments present in the lagoon before and after restoration. Prior to restoration, the easternmost stations experienced extreme swings in salinity and temperature (see water quality data in Chapter 5). The changing environment in this portion of the lagoon may have acted to depress the abundance of organisms within the space. Following restoration, the easternmost stations became relatively stable with regard to salinity and temperature fluctuations. This muting of extreme conditions may explain the greater infaunal densities in the east basin following restoration. The east basin is characterized by muddy sediments high in organic content (see Chapter 3). These sediments can support large numbers of small opportunistic species (Pearson and Rosenberg 1978) if the species present are not impacted by other physical parameters.

Infaunal trends between tidal elevations (-2 feet, +1 foot, and +3 feet MLLW) were not clear for several reasons. Samples were collected at the same location during each sampling event. However, the actual elevation at the –2 and +1-foot stations did not remain consistent over time. At most stations, there was infill due to incoming sands (west and central basin) or sedimentation (see Chapter 2) that effectively raised the elevation of some sites. Counteracting that effect, however, was the gradual increase in tidal muting, which affected the duration of inundation at these lower elevations as less lagoon drainage was achieved at low tides. Therefore, the environmental conditions experienced at each sampling station and elevation were inconsistent over time and likely obscured the ability to detect clear trends between the elevations. Additionally, considerable variation in sediment type existed between replicates within a given station and elevation. For example, at the +1-foot elevation at Station 1, the sandy substrate was intermixed with patches of very dense clay, so the randomly selected sites for core collection often fell in areas of different or mixed substrate type. At the –2-foot elevation at Stations 1 and 2, the hard clay ridges left by the restoration dredging alternated with unconsolidated fine silt in the troughs between ridges. Variability in conditions existed between stations as well. The +3-foot elevations at Stations 1, 3, and 5 all occurred in sandy sediments, while at Stations 2 and 4, the +3-foot elevation was composed of dense clay (Appendix A8-2). Three-fold replication was not adequate to compensate for the intra-station and inter-station variability.

Similar to infauna, the shift from fresh and brackish water epifauna to marine species was rapid in the epibenthic macroinvertebrates. Sampling conducted during the pre-construction surveys (WRA 1994) and during construction (WRA 1997) noted that this shift was already progressing as a result of flooding the lagoon with seawater for the purpose of facilitating dredging. During 1994, insect larvae dominated epifaunal collections. During construction in 1996, caridean shrimp were the most abundant organisms represented, with insects limited to predaceous water beetles (*Dytiscidae*) at a single station (WRA 1997).

Species present shortly after the lagoon opening were all marine species associated with estuarine or bay environments. Initially, species tended to arrive in pulses, with captures of species such as *B. gouldiana*, the non-native white bubble snail *Philene auriformis* (observed prior to regularly tracking of epifauna), *N. inermis*, and *H. californiensis* in very high numbers in some quarters, then in very low numbers in others. Over time, the variability in epibenthic community composition appeared to decrease between sampling intervals with species such as *B. gouldiana* (56% of total), *H. californiensis* (18% of total) and *A. ventricosus* (12% of total) emerging as consistently most abundant. *Nassarius tegula*, *N. inermis*, and *Alia carinata* each made up 3% of the total, and in the later post-restoration monitoring years, less dominant organisms were observed more regularly, but in small numbers.

The incorporation of quarterly sampling of epibenthos as a part of the fish surveys provided much more useful and comprehensive data on the composition of the epibenthic community. Although the technique has limitations for quantitative density analysis, it is an efficient and cost effective way to characterize the epibenthic community.

For both infaunal and epifaunal data collected, examination of community parameters, such as diversity and evenness, are beyond the scope of this monitoring program given the limited taxonomic identification performed; and therefore, community comparisons across the lagoon were not made. Moreover, the lack of lower level taxonomic data make it impossible to compare the relative health of the Batiquitos Lagoon benthic communities with some popular indices (*e.g.*, Index of Biotic Integrity, Benthic Response Index) to local reference standards. With that said, the basic goal of the sampling program was met; monitoring allowed observation of the conversion of the lagoon's invertebrate community to one reflective of other tidally influenced bays and estuaries.

Ten years post-restoration, Batiquitos Lagoon supported epibenthic and benthic invertebrate communities that were diverse and abundant. This means that the marine fish and birds present at the lagoon had a substantial and evolutionarily relevant prey base. The long-term maintenance of this resource will mean the maintenance of ecosystem functions that support fisheries and marine birds.

8.4 RECOMMENDATIONS

The maintenance of the invertebrate resources at Batiquitos Lagoon requires tracking of two management priorities. First, tidal exchange needs to be maintained through periodic dredging of the entrance channel and channels connecting the basins. Second, discharges of pollutants and sediments into Batiquitos Lagoon from upland sources need to be minimized. Below are specific recommendations to help achieve these management goals.

- Implement recommendations made in Chapter 2 relating to the regular and extended maintenance dredging to maintain tidal exchange throughout the lagoon.

- Initiate a program to monitor sediment inputs into the lagoon to better understand the source, rate, and periodicity of inland-source sediment loading.

- Sample periodically to document and track the spread and impact of the invasive Japanese mussel (*Musculista senhousia*).

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